Exploitation effects on propagation of *Argania spinosa* in Morocco

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2017
Morocco
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Submitted in 2017 in partial fulfillment of the requirements of the Student Project for Amity among Nations (SPAN), as organized under Foreign Studies Seminar Program 5970W (Writing Intensive) at the University of Minnesota. This Project was completed in accordance with the Institutional Review Board Study Number 1203S 12061.

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Acknowledgements

This research was made possible by the Student Project for Amity among Nations (SPAN) research abroad program in cooperation with the University of Minnesota – Duluth, University Honors Program. I would like to thank Drs. Ryan Goei and Dana Lindaman for their support and efforts to make the experience possible, and Dr. John Pastor for his assistance and recommendations in completing this final report. This work was financially supported by the Ruth Elliff Memorial Scholarship, the Dean and Janet Lund Scholarship, the Kathryn M. Sederberg Memorial Scholarship, the John D. Lindstrom Scholarship, and the UMD Study Abroad Scholarship. I would also like to thank the Outalb family for opening their home to me while in Morocco and for providing me with their knowledge on the argan forests.

Figure 1. K. Outalb, S. Arens, R. Goei, D. Lindaman, in Bel Bayad, Moroccan argan forest.

Abstract

Argania spinosa, the argan tree, is endemic to Morocco and provides many ecosystem services for the Moroccan people, as well as people around the world; these include oil production for domestic use or sale, shade for growing crops, grazing areas for livestock, and providing soil stability that helps prevent desertification and climate change. High demand for argan oil has created a market for seeds, thereby providing income for many local people. As demand for the oil rises, the argan forests have become exploited. Argan trees cannot effectively reproduce with high levels of farming, seed harvest, and grazing. Without proper management and regulation of forests, they could be lost and replaced by deserts. This study's aim is to evaluate how different kinds of exploitation affect natural reproduction in *Argania spinosa*. Four different study sites were chosen to represent varying levels of exploitation by comparing the effects of farming, grazing, and humans on argan reproduction. Forest plots were sampled in each region to identify young sapling densities compared to adult tree densities, and seed dispersal ranges were compared to identify the effects of exploitation on propagation. Although seed collection pressures have rapidly increased in the past decades, the results of the study suggest that agricultural pressures from farming within argan forests may decrease argan tree propagation.

Figure 2. Argan forest area in Bel Bayad, Morocco.

Introduction

The argan tree, *Argania spinosa,* is endemic to southwest Morocco (Defaa et al. 2011). Moroccans harvest argan seeds for oil and extract firewood for fuel (le Polain de Waroux & Lambin 2012). Trees are also browsed by livestock, and used as shade sources for various crops (Alados & El Aich 2008). Argan oil exports are steadily rising because of increased use in beauty supplies and hair products, and argan oil is currently the most expensive edible oil available for purchase (Lybbert et al. 2011).

The argan forests contribute to the country's development ecologically, economically, and socially (High Commission for Water and Forests and Fight against Desertification 2009). Argan trees not only support local economies, but the forests help prevent desertification of the Sahara Desert by maintaining soil stability. Preventing soil erosion helps to maintain nutrient levels in the soil. However, the pressure put on the trees by grazing, cutting, farming, and climate change are all potentially detrimental to the argan forests.

In order to maintain sustainable *A. spinosa* populations, regulation of these forests is necessary. Management plans have been created to best support *A. spinosa* populations, but such protection plans may be hard to abide by for those who rely on the argan forests for income. Village communities have been self-managing tree populations for decades, so new government rules pertaining to *A. spinosa* management are extremely controversial. It is important that management plans for the argan forest are implemented and enforced for the future conservation of argan trees in Morocco.

Background Information

Argania spinosa has always been a nourishment source for both people and domestic animals, a healing source, a cultural and mythical system in everyday living, and important during festivities because of the many services the tree provides (Aziz et al. 2011). The argan tree dates back some 65 million years, and was the second forest species in Morocco after the green oak (Alaoui 2011). Currently *A. spinosa* covers approximately 870,000 hectares at a density of 10-50 trees per hectare (Alaoui 2011). The tree is well adapted to the arid conditions and high temperatures that are characteristic of the southwest region of Morocco, (Aziz et al. 2011). Unlike the olive tree, the argan tree requires very little maintenance or water (Aziz et al. 2011). However, because of excessive human exploitation, the tree is currently under great threat (United Nations Educational, Scientific and Cultural Organization 2002).

Socio-Economic Impacts of Argan

Traditionally, the argan tree has provided for the Moroccan people through pastoralism, food, forestry, medicine, and cosmetics (United Nations Educational, Scientific and Cultural Organization 2002). However, in the 1990's, argan oil started to be used for culinary, cosmetic, and medicinal purposes by foreigners. Demand and price of the oil has increased with time, and the people of Morocco have taken advantage of this growing market. Previously, argan products were not frequently exported and were primarily used for self-consumption (Aziz et al. 2011). Between 1999 and 2007, household oil production increased threefold and the number of households selling the oil doubled (Lybbert et al. 2011).

The high price of argan oil in the market has created a local awareness of protecting the fruits of *A. spinosa*, but has not necessarily created an overall view of protecting the tree population for sustainable harvest (Lybbert et al. 2011). Merchandizing the oil has had both positive and negative effects on the Moroccan Kingdom (Aziz et al. 2011). Although selling the oil is profitable, the high demand for fruits can be detrimental to trees when degradation and overexploitation occurs. With the new high demand market, the fruits become scarce at times (Aziz et al. 2011). Finding an ecological, social, and economic balance of the argan tree is largely important for the Moroccan people (Alaoui 2011).

Figure 3. Traditional method for cracking open argan nuts to obtain seeds for oil extraction.

Positive effects of market rise include the more than 7 million person days of work per year for Moroccan families that the argan trees provide (Alaoui 2011). The market for argan oil and its products has created a larger market for the fruit and all of its derivatives (Aziz et al. 2011). Unlike crops, including cereals such as wheat and barley, that sell for similar or lower prices than their cost prices, the argan tree is the only income source for some families (Aziz et al. 2011).

Argan income has become especially beneficial for women in Morocco. The money allows them to satisfy their personal needs as well as contribute to their families'. This monetary autonomy equalizes income contributions between husbands and wives because now both men and women take part of the financial decision-making for the family (Aziz et al. 2011).

Intermediaries and private buyers are one consequence of the high argan demand. These operators make up most of the oil market and only seek short-term benefit (Aziz et al. 2011) . The removal of income from the local Moroccan markets and into external buyers for foreign sales separates the income to an even greater extent (Aziz et al. 2011). It takes away potential income for Moroccans living in villages to large cities or even outside of the country. This has created a disproportionate power where middlemen control revenue within the argan market that has both socioeconomic and cultural consequences (Aziz et al. 2011). However, local populations have benefited from the demand, in some instances, by creating cooperatives, intermediaries, and industrialists because these cooperatives purchase fruits in large quantities to meet consumer requests (Aziz et al. 2011). The changes in supply and demand consistently influence fruit and oil prices (Aziz et al. 2011).


Figure 4. Drying argan fruit before nuts are removed for seed extraction.

The oil is used for both cosmetics and food, but the price of cosmetic oil ranges from 300-800 Dirhams/L in cooperatives (about $30-80 US) (Aziz et al. 2011) which is greater than that of edible oil which sells at about 250 Dirhams/L ($25 USD) in the local Moroccan markets (H. Outalb, Personal communications with the author, Nov. 2017). The edible oil comes from roasted kernels and the cosmetic oil comes from raw kernels (Aziz et al. 2011). The roasting of the seeds makes it possible to produce more oil, so the difference in price of cosmetic and edible oil makes up for this loss in volume when not roasted. Most cooperatives prefer to produce cosmetic oil because of its higher sale price (Aziz et al. 2011). Another justification for the cost difference is that most cosmetic products are sold abroad where buyers are willing to pay a higher price (Aziz et al. 2011).

Any or all parts of the whole argan fruit are also sold for various prices depending on their value. After the fruity endocarp (Agaleem) has been dried and removed from the nut, it is usually used as animal feed. After the hard shell nuts (Arress) have been cracked, they are used for fuel for fires within homes or are sold (K. Outalb, personal communication, June 2017). The shells can sell for about 0.5 Dirhams/kg (about $0.05 USD) and are often bought by intermediaries who sell them to Moorish baths or bakeries for fuel purposes (Aziz et al. 2011). Other times, the shells are used as a decoration for furniture (K. Outalb, personal communication, June 2017). The seeds (Zneen) inside the nuts are pressed to obtain oils, and the extracted remains (Zagmouna) are given to animals for feed (K. Outalb, personal communication, June 2017). Two hundred grams of zagmouna usually varies in price ranging from 1.8-2.5 Dirhams (about $0.18 - 0.25 USD) (Aziz et al. 2011).

***A. spinosa* Natural Reproduction**

A. spinosa is a slow-growing spiny tree that reaches about 10 m at maximum height (Zunzunegui et al. 2010). The argan fruit is a drupe enclosing one nut that contains between 1-3 seeds (Nouaim et al. 2002). Extracted oil comes from the seeds inside these nuts. The argan tree shows a significant production of fruits every other year (Aziz et al.

2011). Flowering begins in the spring and lasts throughout the fall, while fruit production lasts from April until September (Zunzunegui et al. 2010).


Figure 5. Recently fallen argan fruits in loubia farm plot.

Argan stands are especially susceptible to anthropogenic pressures as the almost nonexistent natural regeneration shows (Belghazi et al. 2011). Because of this difficulty, artificial regeneration efforts have greatly increased in the past few decades. Replanting argan trees as a form of reforestation effort is often unsuccessful. Many factors, including human pressures and animal grazing, affect seedling survival.

Seed Dispersal Mechanisms

Finding information on seed dispersal mechanisms was extremely challenging. This was likely because of the lack of English publications related to argan trees. However, French publications related to the specific subject of seed dispersal mechanisms and abilities were also rare. This emphasizes the importance of a study such as this to contribute to basic knowledge about the species. French publications were primarily used as background for the study, but it should be noted that translations may have created minor discrepancies in interpretation.

The argan trees disperse their seeds by dropping hundreds of fruits. Various studies have suggested different mechanisms for dispersal of the seeds. These include: endozoochory by goats and other animals consuming the fruits (Delibes et al. 2017), proximal dispersal from seeds falling next to parent trees, as well as artificial plantings (Belghazi et al. 2011).

Many sources claim that goats consume and defecate argan nuts that are later collected and used to produce argan oil. On 15 May 2016, CBS reported, “Argan nuts pass through the digestive system of a tree goat whole (www.cbsnews.com/pictures/tree-goats-of-morocco-argan-oil/). Once they are excreted, people gather them from the goat’s droppings and crack them open to expose the seeds inside.” This is not an uncommon theory. Other popular news sources such as Huffington Post, also have written articles about the strange practice of fecal matter seed collection (Greenwood 2015). However, new research proposes that this is a misconceived idea on how goats actually transport argan seeds.

NPR recently discussed research done by Delibes et al. (2017) suggesting that the long-lasting myth about goats defecating nuts for collection is likely untrue (Silver 2017). Their studies found that goats are physically unable to defecate argan nuts because of the sheer size being, on average, about 22 cm. However, they found that it is very likely that goats do transport consumed seeds through regurgitation and spit out cud (Delibes et al.

2017). It is common for seeds to remain in the rumen for hours or days, so rumination is a good long-distance seed dispersal method.

Although the mode of transport within goats may be different than initially perceived, goats likely still play a large role in argan seed dispersal. Because research of this kind is rather new, it is likely that in upcoming years, more research will be done looking into endozoochory of argan seeds in other grazing animals, such as donkeys and sheep.

Exploitation of *A. spinosa*

Overexploitation

Human populations in arid zones often taken advantage of plant resources from a small number of plants or from one individual species (Cruz et al. 2010). Harvesting, cutting and grazing of argan trees can be beneficial for community income, but can be detrimental to forest health. Overexploitation and degradation may be inevitable when communities rely on a limited number of species or populations for their own living purposes. Loss of trees and lack of regrowth has diminished tree densities (le Polain de Waroux & Lambin 2012). Throughout the last century, deforestation of the argan forest has eliminated trees at a rate of 600 hectare per year (Alaoui 2011). Overexploitation causes *A. spinosa* to be subject to constant stress and human disturbance (Zunzunegui et al. 2010).

Harvesting and Cutting

Native harvesters tend to use methods that are harsh on the trees to obtain fruits during harvest. Sticks are often aggressively used to dislodge fruits from trees. This method can result in dislodged buds that prevent future growth as well as breaking branches from trees (Defaa et al. 2011).

Wood sale has also become a major source of income in dry years (le Polain de Waroux & Lambin 2012). Even though fruit prices are high, people have shifted toward using dead argan trees as an energy source instead of butane (Lybbert et al. 2011). Argan wood is also used for carpentry and craft-making (Zunzunegui et al. 2010). In 1999, 17% of households used argan wood for cooking, while nearly 67% of households use the wood for cooking in 2007 (Lybbert et al. 2011). This shift is largely because of increased butane prices and free access to argan wood for burning (Lybbert et al. 2011). Although cutting live argan trees and branches is illegal (Lybbert et al. 2011), many Moroccans acknowledge that cutting of trees has been partly responsible for forest decline (le Polain de Waroux & Lambin 2012).

Agriculture

The expansion of agriculture is another main factor pertaining to the loss of argan trees. Argan forests are often exploited by local farmers when the trees are used as shade for cereal crop growth which is important to the local economy (Karmaoui 2016). High agricultural pressures greatly impact soil stability because soil is so frequently upturned when tilled or crops are planted. This disruption to soils not only prevents seeds from germinating, but it also removes important nutrients from the soil. Such exploitation can greatly reduce natural reproduction.

Seed Collection

Systematic collection of the fruits also prevents natural regeneration by sowing (Defaa et al. 2011). It is beneficial for argan seed collectors to gather every fallen argan fruit from a tree. The more fruit a person obtains is directly related to how much oil can be produced and therefore a greater income from fruit harvest. However, when every fruit is removed from the plot where it was naturally dispersed by the adult trees, it eliminates any chance of natural regeneration.

Grazing

Increasing numbers of goat herds continue to be a concern for argan forests (Lybbert et al. 2011). Grazing by livestock, primarily goats, but also by dromedaries and sheep is very common. The argan leaves act as elevated grasslands for browsing (le Polain de Waroux & Lambin 2012, Zunzunegui et al. 2010). Herbivory has consequently caused steady decreases in

Figure 6. Argan forest plot near Taroudant, Morocco grazed on by goat herds.

wooded area density. When animals graze on the leaves, there is a reduction in plant fitness because of lowered leaf area. The loss in leaf area decreases carbon assimilation and nutrient uptake of the plant (Zunzunegui et al. 2010). This loss in photosynthate nutrient resources suppresses functions that the plant needs for growth, maintenance, and reproduction (Zunzunegui et al. 2010).

Households have benefited from argan sales, and this larger income has allowed households to accrue more assets. These assets are often in the form of goats. However, goats climb the argan trees to graze and can negatively affect the health of *A. spinosa* populations (Lybbert et al. 2011). High value argan oil extractors insist on only purchasing whole fruits in markets to guarantee that goats have not previously digested the seeds. This has created a spike in fruit prices and has also prevented locals from allowing goats to ingest whole fruits (Lybbert et al. 2011). Most households allow their goats to graze in argan trees, but grazing has become less frequent and monitored and is especially rare during the argan fruit collection season (Cruz et al. 2010, Lybbert et al. 2011).

Global Climate Change and the Argan Forests

Desertification

Desertification is the impoverishment of arid and semi-arid ecosystems by impacts including drought and human activity (Dregne 1977). According to the United Nations Educational, Scientific and Cultural Organization, the argan forests grow along the

Sahara Desert's border and functions as a buffer against desertification (2002). When soil becomes bare, the soil surface and air temperatures rise. Dry and hot soils slow nitrogen accumulation that promotes shrubland spread (Schlesinger et al. 1990). Drought and low nitrogen availability stress the plants and can lead to the development of arid ecosystems. Changes in ecosystems can be influenced by human impacts and large-scale climate change (Schlesinger et al. 1990). A large increase in arid lands will increase albedo and will likely affect regional climates by further decreasing regional rainfall (Schlesinger et al. 1990). Desertification of smaller lands will also cause more episodic precipitation events with an increased frequency of extreme rain events (Schlesinger et al. 1990).

Aridity of the climate plays a large role in degradation of argan forests in Morocco. Irregular rain patterns cause a decline in vigor of *A. spinosa*, increased mortality, and a decrease in forest density. Aridity also minimizes the chance of germination for the few seeds that, in very rare cases, actually are dispersed on the ground (Defaa et al. 2011). These climate changes and the increasing lengths and frequencies of droughts kill argan trees (le Polain de Waroux & Lambin 2012). This may provide more dead wood for harvest, but will depress oil production and other services the trees provide. The argan tree is well adapted to stresses of occasional severe drought (Chakhchar et al 2015), but if the drought becomes too common, current ecosystems may no longer be suitable for the argan tree to survive.

Soil Stability and Erosion

Argan forests protect against soil erosion and desertification, as well as helping to maintain fertility of the soil in an arid climate (Zunzunegui et al. 2010). Belghazi et. al, showed that deep soils developed on dolomitic limestone, and gentle slopes, where shrub and herbaceous coverage is minimal provided the best conditions for seedling growth (2011). Argan's role in soil stability is largely because of its extensive root system (Alaoui 2011). These roots not only prevent erosion, but they can also provide stable habitat for other species' growth. However, because of human activities in semi-arid lands, dust storms have become increasingly more frequent (Schlesinger et al. 1990). Eroded soils that have low nutrient levels will have low fruit crop volume and seed size (Zunzunegui et al. 2010).

Environmental Effects

The argan tree has a strong role in structuring ecological communities. As a "relict of the Tertiary Period, this forest species is extremely well adapted to drought and other environmentally difficult conditions" (United Nations Educational, Scientific and Cultural Organization 2002). Over 1,200 species of plants and animals rely on *A. spinosa* in the North African region (Lybbert et al. 2011). Argan trees also provide shade for various types of crops (Zunzunegui et al. (2010). The increased demand for *A. spinosa* is benefiting some people, but has also negatively changed forest environments. Argan forests in the northern region have greatly thinned since the boom in argan oil exports (Lybbert et al 2011). The 2010 Global Forest Resources Assessment in Morocco showed that forest size decreased by 11,100 ha between 1990 and 2005 (Defaa et al. 2011). Short-term fruit collection incentives have increased, while long-term forest sustainability has become a concern.

Argan Forest Management and Regulation

History of Argan Land Governance

The Moroccan land management structure was originally based on religious principles that specify whoever gives life to a land becomes its owner. The exception to this policy is that forests do not belong to any one person because they provide general utility to a community including firewood and grazing (High Commission for Water and Forests and Fight against Desertification 2009).

This system was subject to riparian tribes' rights because they often would consider themselves owners of the forest areas. At this time, the main protection concerns were for grazing, clearing, and various wood uses. These tribe members took argan products without any regulation which led to controversy when the Sunnah (way of prophet) specified the exception of forest land from personal ownership. Until the Dahirs (Moroccan King's decrees) of 1917 and 1925, the rights of the lands were uncontrolled (High Commission for Water and Forests and Fight against Desertification 2009).

Arganeraie Biosphere Reserve

The increased demand of argan oil has increased exploitation of argan trees across Morocco. Conflicts about argan resources and permanent barriers have resulted (Lybbert et al 2011). Many organizations are currently working on argan tree management and study including: coordinating scientific research, development and protection of natural balances, legal protection of exploitation, improvement of standard of livings for populations relying on argan for income, assuring quality of argan products, and continually updating argan tree data (Alaoui 2011).

The Réserve de Biosphère de l'Arganeraie (RBA) is designated under the United Nations Educational, Scientific and Cultural Organization (UNESCO) Man and Biosphere Programme (MAB) as a biosphere reserve. The reserve in Morocco consists of an area of argan forest of approximately 23,690.3 km^2, and became designated in 1998. The governance of the land is under the power of the national ministry, and the High Commision of Water and Forests is the responsible management authority (United Nations Educational, Scientific and Cultural Organization 2002).

Conservation Efforts

Authorities', including the Office for Water, Forests and Desertification Control (HCEFLCD), list their main objectives as resource conservation and timber production (Defaa et al. 2011, Genin & Simenel 2011). However, Moroccan populations have been shaping argan forests through domestic management systems for decades. Methods include differential cutting or trimming, determining type, structure, and level of resources, as well as using complementary forest areas for particular functions (Genin & Simenel 2011). Some argue that a domestic forest should integrate production and conservation with political, social and spiritual interactions. However, authorities often overlook internal management systems as ecological and social impacts are poorly documented (Genin & Simenel 2011).

Improving knowledge about the species through research is important for its usage and physical conditions, as well as having socio-economic advantages (United Nations Educational, Scientific and Cultural Organization 2002). Regeneration of the argan tree has been facilitated by various levels of coordination between adjustments to soil, exclosures, protection of shoots, and overall organization and uses of landscapes (Genin & Simenel 2011). Methods currently used for management include regulation of periodic cutting where it may be allowed every day or only during specific days. An agdal management system specifically divides regions for self-governance of resources. They create a rotating system for shared forest management where certain rights pertaining to the land use are only granted during specific periods. Rules are created and enforced by local populations to allow them to manage their own territory. Quantities of harvest may be regulated by quotas depending on family sizes or by equal quotas. Agdal divisions can also allow for rotational cutting by sector (Genin & Simenel 2011).

On a smaller scale, some cooperatives have made efforts to cope with the risk of fruit scarcity. They have opted to store more fruits by purchasing them from various sources (Aziz et al. 2011). According to cooperative members, in some areas, protecting the seedlings and young argan trees has been practiced as knowledge about the trees' environment and conservation interests increase (Aziz et al. 2011). This shows how community awareness of the value of the resource often motivates conservation efforts (Aziz et al. 2011).

Science Supporting Regulation

Historically, mountain populations of the argan tree were the only populations without high herbivory pressure. In recent years, coastal and Mediterranean populations have been protected from herbivory by constructing fences around their perimeters (Zunzunegui et al. 2010). Argan trees that were protected from herbivory and experienced better climatic conditions had more and larger fruits (Zunzunegui et al. 2010). Although current forest density is the lowest in coastal regions, these populations appear to be the most favorable for argan oil production (Zunzunegui et al. 2010). Inland ecotypes of *A. spinosa* also seem to be more drought-tolerant and thus are promising for regeneration of argan forests (Chakhchar et al. 2015).

Other scientists argue that genetic diversity by measure of allelic richness should be given priority for conservation. They consider allele preservation to be more important than maintaining allelic frequencies. Mountainous populations seemed to have higher allelic diversity, (Petit et al. 1997) but this was not surprising because mountain populations undergo harsher changes in climatic conditions and often have less grazing pressure.

Current Management

On March 4, 1925 an official decree by the Moroccan King established land regulation that pertained particularly to the argan forests. Under this decree, definitions of citizens' rights pertaining to tree delimitation, their fruit, and land use were created. Land that previously was unforested and was planted by native tribes is under the complete management of those who created it. The protection of afforested plots is also important because they now play an essential environmental role, even though they were not previously argan forests. These forest plots of land belong to the indigenous tribes but are still protected under the same regulations as other argan forest plots. The rights of use on afforestation includes: collection of dead wood, fruit picking, the herd route, land use, cutting firewood, charcoal and service, cutting of fence branches, and removal of soil, sand, and stone. (Dahir on the protection of the delimitation of argan tree forests 1925).

Laws Pertaining to Argan Forest Usufruct

Forest authorities are not alone capable of controlling and micromanaging all argan forests to the extent needed. To resolve this issue, a usufructuary forest management system was implemented where local communities are allowed to use the government land for their own needs as long as regulations are abided by. Villages divide up allotted argan forest areas into plots for villagers to plant crops in. The Moroccan Forestry

Administration recently began recognizing the importance of local populations' opinions when creating an efficient management plan (Genin & Simenel 2011). Local visions of forest management often differ from those of forest authorities, so identifying conflicts and searching for ways to resolve them is key to promoting healthy forests as well as supporting communities.

There are certain rights under the usufruct system that all Moroccan citizens are entitled to. Under Article 2, of the Decree of 7 March 1950, users are entitled to the collection of dead wood lying free at all times for their own needs, and under Article 3, fruit picking is free everywhere at all times. This allows villagers to collect dead wood and fruits from any forest plot at any time, no matter if the plot is under their management or not (Dahir on the protection of the delimitation of argan tree forests 1925).

There are also rights that are reserved for the individual's responsible for farm plots within the argan forest. These include the right at harvest time to enclose their usufructuary plots with a temporary fence. Under Article 5, villagers' right to use the forest land includes the right to plow and cultivate plots that were already cultivated at the time of delimitation. In cases where plots are not yet cultivated, the forest service has final judgement on deciding if it is considered safe for the forest (Dahir on the protection of the delimitation of argan tree forests 1925).

Any type of clearing or cutting of forest species is strictly prohibited. However, uncultivated shrubs can be disposed of except on steep slopes where extraction of standing shrubs is forbidden. Users are permitted to cut trees, under Article 6, in the form of collecting free firewood intended for personal use by pruning trees. They may also prune trees within their plot under Article 7, if necessary, to create fencing if cutting bushes of the undergrowth is not sufficient enough.

Article 15 discusses the use of erect tents or the construction of flammable materials. They may be authorized within a certain distance of the forest if the forestry service should approve. Article 9 states that users of the argan forest must pay for all forest products that are used in ways other than domestic needs. However, fruits of the argan tree and their derived products are not included in this provision (Dahir on the protection of the delimitation of argan tree forests 1925).

Summary

With increasing global temperatures and overexploitation and degradation of argan forests, desertification of the Sahara desert has become a concern, especially in border areas of the desert in Morocco. The argan forests provide soil stability, help prevent erosion, and provide a source of income for many Moroccan people. Argan trees are able to help fight warming temperatures by preventing desertification, but are also subject to changing environmental pressures. Exploitation in the forms of grazing, harvesting, seed collection, and farming all affect the health of the argan forests. To best support forest populations, it is important that management plans for argan forests are implemented and enforced. Conflicts between government regulation and pre-existing local regulation have made management difficult. Government policies may be in place, but they are not necessarily effective unless local communities are aware of regulations and are also strictly abiding by them. Working with local communities to create management plans is essential to protecting argan forests while still supporting the Moroccan people and their needs.

Study Areas and Methods

Figure 7. Aerial image of Moroccan argan forest and terrain. Four test plot locations identified by labeled markers. Google Earth images of Moroccan landscape, 2017.

In this study, four plots were identified to study seed dispersal abilities of *Argania spinosa.* All plots were located within the Réserve de Biosphère de l'Arganeraie (RBA) in Morocco. Specific sites were chosen because of their different environmental settings within the argan tree forests.

Location Characteristics and Descriptions

Locations 1-3 (Figure 7) are located within a larger area of argan forest divided into farming plots. This forest is owned by the Moroccan government and managed by the village community of Bel Bayad. Regulations restrict cutting the trees or destroying the forest area. This includes restrictions on building permanent structures in the forest area. However, the village people are allowed to use the forest area freely. They can harvest fruits from the trees, allow their livestock to graze, and use the soils surrounding the trees for growing crops (High Commission for Water and Forests and Fight against Desertification 2009). The plots are farmed to various degrees, and in some cases, several different crops may be rotated through one plot throughout the year. Each plot was separated by some sort of boundary or fencing, depending on the method chosen by the farmer.

Plot number 4 (Figure 7) was located within the same MAB government protected forest system, but was not part of the Bel Bayad village. It had no form of fencing around the plot, yet was still subject to various exploitation factors.

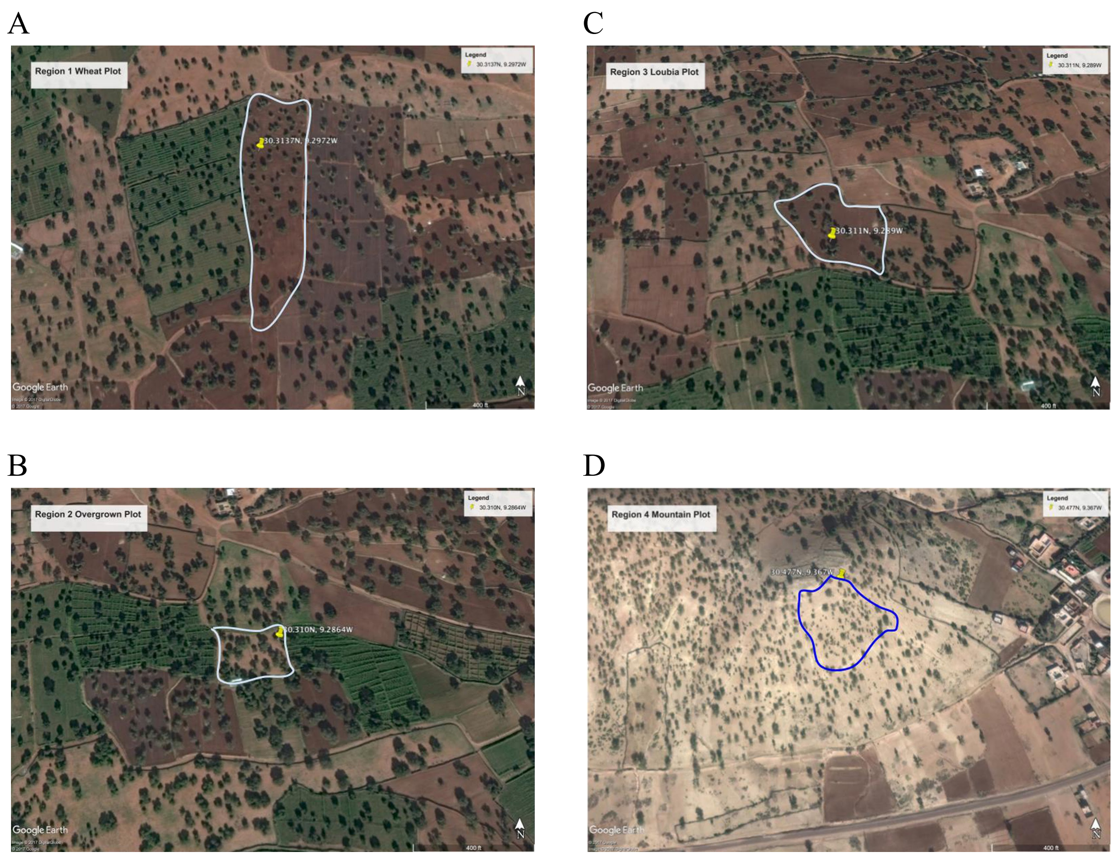
A B

Figure 8. Aerial images of the four study sites in relation to each other. Equal scale Google Earth images of Moroccan landscape, 2017.

Plot 1 (Figure 7) was a harvested wheat field and was chosen because of its high level of exploitation of trees and surrounding soils (Figure 9.A.). Ground grazing by goats, sheep, chicken, and donkeys occurs frequently as well as goats climbing the trees and directly grazing on leaves and fruits. Grazing is easy for livestock because of the very low lying minimal fencing made of dead thorny plants. In several places, the fencing had deteriorated making entry into the plot extremely easy. Harvesting of fruits eliminates almost all remaining seeds from the area. Ground disturbances include crop production, primarily consisting of grain farming, tilling, and to a lesser extent, dry wood collection.

Plot 2 (Figure 7) was an overgrown plot that had previously been used for farming but was currently overtaken by wild grasses and other weeds (Figure 9.B.). Grazing and seed collection are the primary exploitation factors affecting the tree in this area, as the soil had not recently been disturbed for farming purposes.

Plot 3 (Figure 7) was a loubia (Moroccan white beans) field that was partially planted with the beans and partially planted with kasab (cane) (Figure 9.C.). The plot was contained within various means of fencing including stones stacked approximately two feet high and large thorny brush to keep animals out and eliminate grazing pressures. The plot also contained irrigation tubing that lined the rows in the field.



Figures 9. Aerial images of the four study sites, (A) Wheat Plot, (B) Overgrown Plot, (C) Loubia Plot, and (D) Mountain Plot. Images are all of equal scale, and outlined regions designate specific locations of the tested trees in each region. Google Earth images of Moroccan landscape, 2017.

Plot 4 (Figure 7) was located in the foothills of the southwest border of the High Atlas Mountain range alongside the village of Tiwrar (Figure 9.D.). This plot was chosen to contrast the three plots that had heavy agricultural influences, yet was still prone to grazing pressures and seed collection from the nearby village. A steep elevation change made farming in this area unfeasible. It also had large loose gravelly soil which differed from the soils in Plots 1-3.

Methodology for Propagation Measurements

To determine the effects of exploitation on *A. spinosa* propagation, seed dispersal ranges were measured. By locating adult trees capable of reproducing and measuring the density and distance that seedlings and saplings were growing from the parent trees, the dispersal ranges for each plot were determined, and thus the plot's natural regeneration ability. Each plot contained argan trees that were affected by different pressures and were chosen to represent varying levels of exploitation. In each plot, all sampled tree dispersal ranges were used to compare exploitation effects with the number of saplings present.

Geolocation Interpretation

A geolocation plot was created for each region to show approximate density of adult trees and their locations, and to provide identification for individual trees. Locations were recorded for each individual adult tree, so adult trees were given nomenclature with capitalized letters (A-Z, AA-ZZ, etc.). Any adult trees that had produced saplings were recorded with the geolocation data. A geolocation application was used to accurately document tree locations and to create the map (Figure 10). Any plant with a diameter larger than 6 in was classified as an adult tree, and assumed to be capable of producing fruit.

A 200 m plastic measuring reel was used to measure the distance of seedlings and saplings from parent trees. Where adult tree proximal radii overlapped, the young plant was assumed to belong to the closest of the adult trees. Some adults were recorded as the parent for multiple young plants because the saplings all resided in close proximity. For each sapling, the distance from the parent tree was recorded as well as the approximate height of the sapling.

After all data was collected and exploitation values were calculated, the different regions were compared with one another to determine whether or not grazing, seed collection, agriculture, and other exploitation have a negative effect on the argan tree's ability to disperse seeds and successfully propagate.

Results

Plot Density Data

Figure 10 show the geographical distribution of adult trees in each test plot. Plot 1 contained the most adult argan trees (n = 53), but it lacked any young saplings (Figure 10.A.). Forty-five adult trees were found in Plot 2, and there were 4 saplings present (Figure 10.B.). Plot 3 contained 43 sampled trees, and had only one sapling (Figure 10.C.). Plot 4, the Mountain plot, had an overwhelming number of saplings present with

21 saplings from only 28 studied adults (Figure 10.D.). The Mountain plot sapling density was much greater than the three plots located within the forest of Bel Bayad.

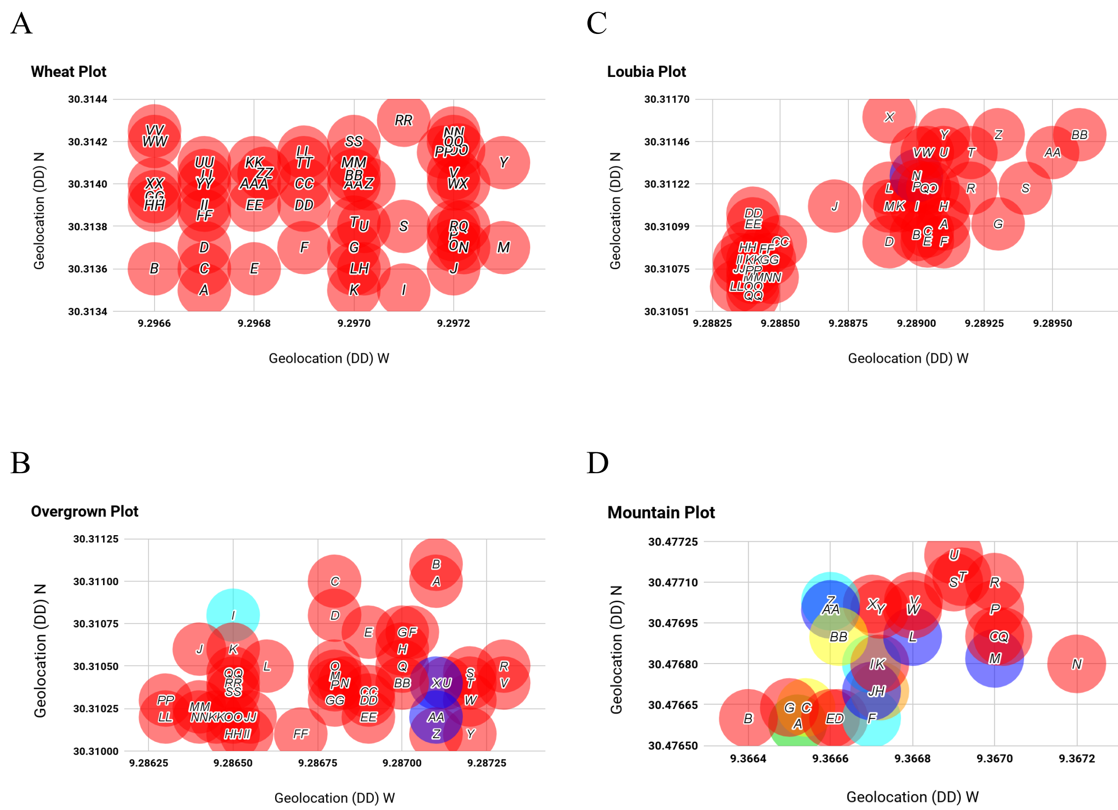


Figure 10. Adult argan tree graphical geolocation coordinate plots of the four tested regions, (A) Wheat Plot, (B) Overgrown Plot, (C) Loubia Plot, and (D) Mountain Plot in Southwestern Morocco, June 2017. Circles represent adult trees. Each adult tree has an individual identification letter assigned from A-Z, AA-ZZ, AAA...etc. Circle color represents the number of saplings associated with each individual adult tree: Red=0, Blue=1, Cyan=2, Green=3, Yellow=4, Magenta=5 (Not applicable in data), Orange=6.

Of the sampled adult trees in each plot, the Mountain plot contained 11 adult trees which were presumed to be the parents to 21 different saplings (Figure 10.D.). Several of the adult trees were responsible for the propagation of more than one sapling as is seen in the varying colors of samples (Figure 10.D.). Plot 2, the Overgrown plot had three propagating adult trees responsible for the total production of 4 saplings (Figure 10.B.).

Plot 4, the Loubia plot, contained only one sapling, and therefore, only had one adult tree that successfully reproduced (Figure 10.C.). Despite the presence of adult trees capable of producing seeds, Plot 1, the Wheat plot, did not contain any saplings (Figure 10.A.).

Exploitation Data

Each plot was scored in three main exploitation categories and given an overall exploitation factor. The bases of this scoring is described in Table 1. The Wheat, Loubia, and Overgrown plot scored similarly in agricultural exploitation level and seed collection level (Table 2). However, the Mountain plot was not farmed or used for agricultural purposes and the soil had not been upturned. The Wheat and Loubia plot were ranked as a 4 because both plots had recently upturned soil because of farming purposes (Table 2). The Loubia plot was currently growing Haricot beans (Loubia) when sites were observed. The Overgrown plot was given a 3 because of its past agricultural exploitation, but was not ranked a 4 because it had been overgrown with weeds and had no indications of a recent tilling of the soil (Table 2).

Figure 11. Recently upturned soil of Wheat plot, Bel Bayad, Morocco.

The exploitation rankings for seed collection were similar between all four of the plots (Table 2). The Wheat, Overgrown, and Loubia plot were maintained by the same community and it can be assumed

Table 1. Exploitation scores were assigned based on various factors and observations associated with the plots. The following describes certain criteria used to score the exploitation of each factor on a scale from 0-4.

Agricultural Exploitation Scale	
0 = None/almost none	There is no farming pressure, soil is not disrupted, crops are not present
1 = Minimal	There is little farming pressure, soil is mildly disrupted, few crops are present
2 = Moderate	There is some farming pressure, soil is intermediately disrupted, moderate crop quantity
3 = Heavy	There is a lot of farming pressure, soil is very disrupted, ample crop quantities
4 = Excessive	Farming pressure eliminates the presence of other species' growth, soil is consistently and heavily disrupted, crop quantities dominate the plot

Seed Collection Exploitation Scale	
0 = None/almost none	All or almost all trees have fallen fruits lying beneath them, people have not collected seeds
1 = Minimal	Most trees have fallen fruits lying beneath them, people have collected fruits from a few of the trees
2 = Moderate	Some trees have fallen fruits lying beneath them, people have collected seeds from several of the trees
3 = Heavy	Few trees have fallen fruits lying beneath them, people have collected seeds from most of the trees
4 = Excessive	None of the trees have fallen fruits lying beneath them, people have collected seeds from all of the trees

Grazing Exploitation Scale	
0 = None/almost none	No animal feces present, branches and leaves appear unaffected by grazing, no animals present, fencing appears permanent and limits all livestock access
1 = Minimal	Little animal feces present, branches and leaves appear mildly affected by grazing, no animals present, fencing appears almost permanent and greatly limits livestock access
2 = Moderate	Some animal feces present, branches and leaves appear moderately affected by grazing, few animals may be present, fencing creates intermediate barrier and allows some livestock access
3 = Heavy	A lot of animal feces present, branches and leaves appear very affected by grazing, some animals may be present, fencing creates little barrier and allows most livestock access
4 = Excessive	Ample amount of feces present, branches and leaves appear excessively affected by grazing, many animals present, no fencing present and all livestock have access

they received similar levels of seed collection. However, in the Loubia plot there was one tree that had several hundreds of fruit lying below it that had not been collected, so its score was lowered to a 3 (Table 2). The Mountain plot was given a seed collection level of 5 because it also had evidence of seed collection similar to the Bel Bayad plots, however, there was one man sitting under one of the trees during data collection (Table 2). This observation implied a heavy continuance of community members entering the plot which would increase its susceptibility to seed collection unlike the three Bel Bayad plots which were located deeper within the argan forest boundaries.

Table 2. Exploitation factors at each test site. Exploitation scores were given to each plot based upon exploitation scoring in Table 1. Plot observations in Southwestern Morocco, June 2017.

Location	Agriculture Level	Seed Collection Level	Grazing Level	**Total Exploitation Factor**
Wheat Plot	4	4	3	**11**
Overgrown Plot	3	4	2	**9**
Loubia Plot	4	3	1	**8**
Mountain Plot	0	5	2	**7**

The grazing exploitation levels of each plot varied slightly (Table 2). The Wheat plot was scored a 3 because there were several remains of goat and donkey feces indicating that animals graze the area frequently, and it had no fencing surrounding the plot (Table 2). The Overgrown plot was given a score of 2 because there was goat and donkey feces scattered, but it had a 2 ft tall boundary consisting of thick brush which may deter some animals from grazing (Table 2). The Loubia plot was partially fenced with a stone wall approximately 2 ft tall and argan and *Ziziphus* thistled shrubs were stacked about another

2 ft above it. The remaining portion of the boundary was fenced with thick thistled branches. Animals likely could not enter the plot because of the fencing, so it was given a grazing exploitation score of 1 (Table 2). The Mountain plot was scored a 2 because there was goat and donkey feces scattered, but not excessive amounts, even though the plot had no fence or border (Table 2). Most of the saplings in the Mountain plot were very short and bushy indicating that they did not have great grazing pressure.

Figure 12. Brush fence surrounding Overgrown plot, Bel Bayad, Morocco.

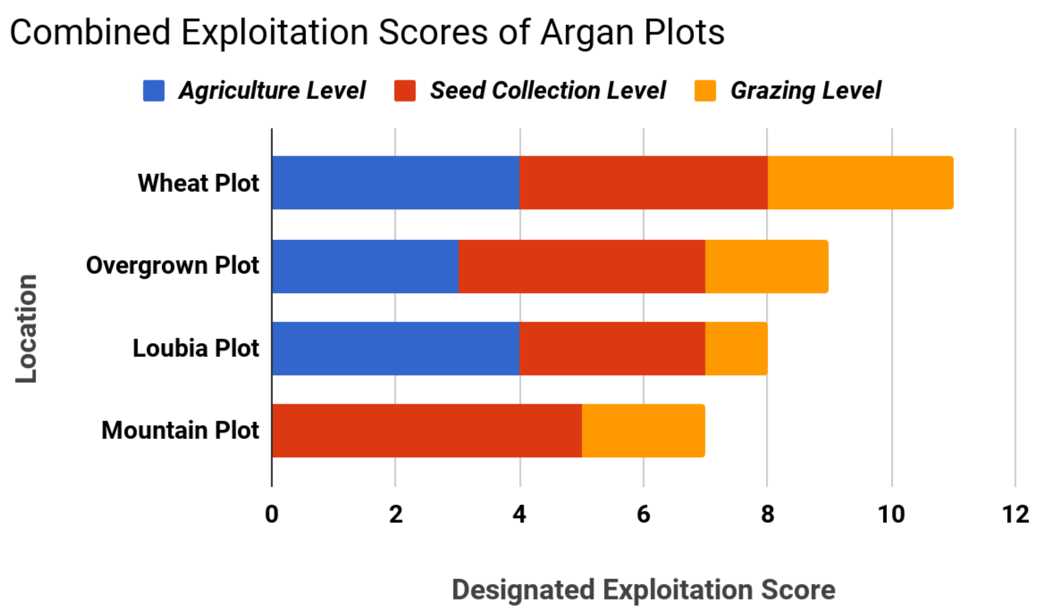


Figure 13. Exploitation levels of four tested argan regions. Representing data from Table 2 to compare specific types of exploitation on each plot in Southwestern Morocco, June 2017.

Figure 13 provides a visual representation of the exploitation scores given in Table 2. The Wheat plot had the most overall exploitation, while the Mountain plot had the least (Figure 13). However, all four plots had exploitation factors within a similar range. The main difference was that the Mountain plot had no agricultural exploitation (Figure 13).

Exploitation Factors Compared With Density Data

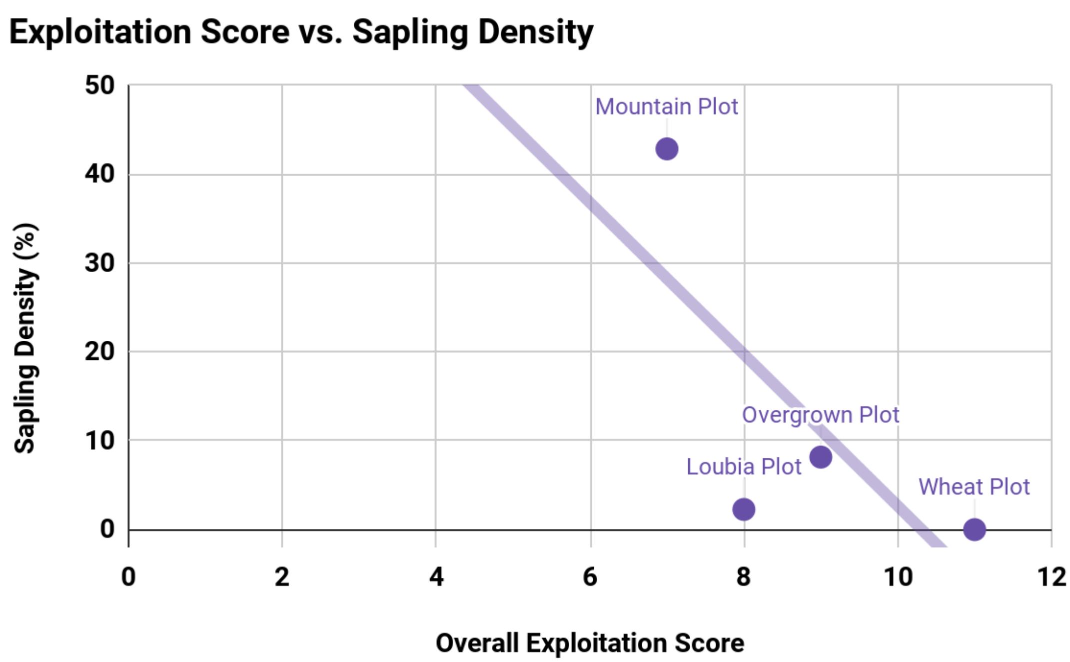


Figure 14. Test plot exploitation level comparison with sapling densities at each location. Trendline shows average exploitation effect on sapling density. Total exploitation factors were calculated from the accumulated exploitation scores (Table 2). Sapling densities were calculated by dividing the number of saplings present by the total number of combined saplings and adult trees within each tested plot in Southwestern Morocco, June 2017.

When comparing the exploitation scores with the density of saplings, the Mountain plot had the lowest overall exploitation score, and the greatest number of saplings present (Figure 14). The Overgrown and Loubia plot had very few saplings and had a middle-range exploitation score, and the Wheat field had the greatest exploitation factor with no saplings (Figure 14). Overall, the four plots follow a general trend of increasing sapling densities with lower overall exploitation with the Loubia plot being a slight outlier to the trendline (Figure 14).

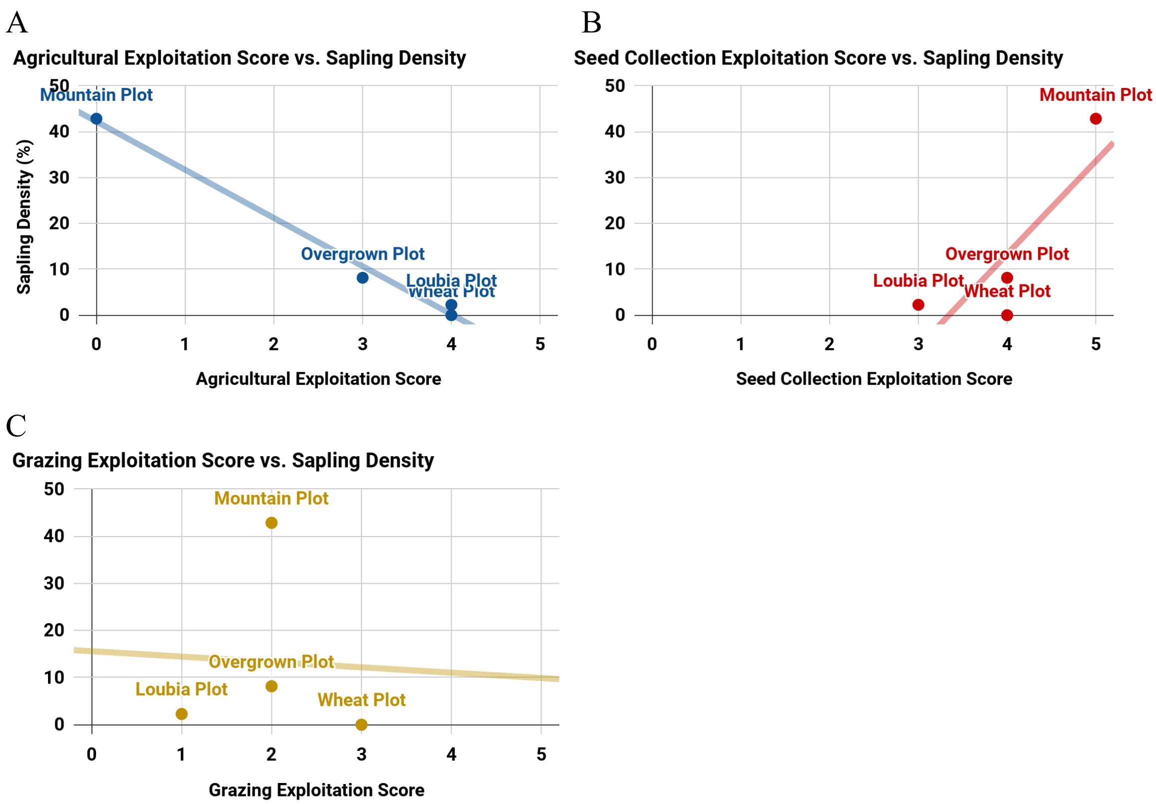


Figure 15. Test plot exploitation factor levels compared with sapling densities at each location. Sapling densities were calculated by dividing the number of saplings present by the total number of combined saplings and adult trees within each tested plot. Trendlines represent correlation between specific exploitation factors and sapling densities. Exploitation percents were calculated by dividing the designated exploitation score by the combined total overall possible exploitation factor. Observations and designated exploitation factors from test plots in Southwestern Morocco, June 2017.

When comparing each exploitation factor individually, only the agricultural exploitation had a direct correlation with sapling density (Figure 15). The Wheat and Loubia plot both had fairly high levels of agricultural exploitation and close to zero sapling presence (Figure 15.A.). In the Overgrown plot, where agricultural pressures were slightly less than in the Wheat and Loubia plots, there is correlated increase in sapling survival (Figure 15.A.). In the Mountain plot, where no agricultural pressure exists, 21 saplings were able to thrive.

The trendline in Figure 15.B. shows close to no correlation between grazing pressure and sapling densities of the plots. The seed collection exploitation actually follows a general positive trend showing that sapling densities increased with higher exploitation factors (Figure 15.C.).

Reproduction Dispersal Data

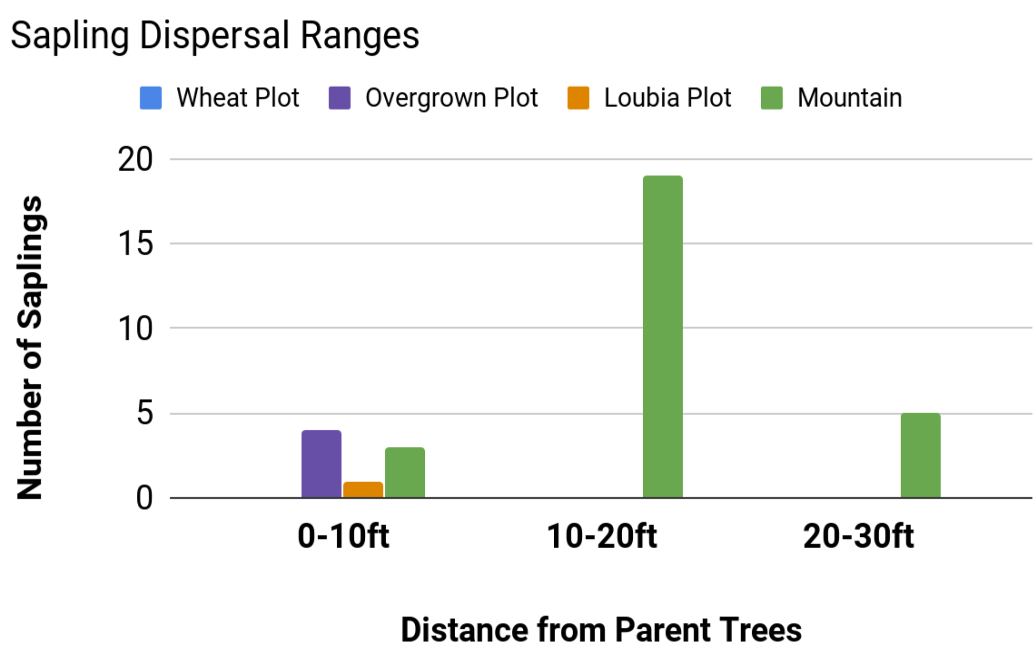


Figure 16. Distance and abundance of saplings from parent argan trees. Color represents specific test location in Southwestern Morocco, June 2017. Distances of saplings from parent trees were measured using an open reel measuring tape. Saplings were assumed to belong to the nearest adult tree within its proximity. The Wheat plot had no saplings present and therefore has no represented data in the figure.

When comparing the distance range of saplings from their parent trees, the Mountain plot had the greatest number of saplings between 10-20 ft (Figure 16). There were fewer saplings between 0-10 ft, and 20-30 ft of range (Figure 16). For the Overgrown plot and the Loubia plot, all saplings were within 0-10 ft of the parent trees (Figure 16).

Additional Scientific Observations Related to the Study

Figure 17. *Theba pisana* on argan branch in Overgrown plot, Bel Bayad, Morocco.

Wheat plot observations include extremely open and dry topsoil. Very few vegetative species were growing in the plot other than *Ziziphus.* It seemed to thrive under the areas near the trees where argan canopies provided shade for them. The *Ziziphus* shrubs could be easily mistaken for young argan saplings if not carefully observed. It is possible that these plants compete with young argan saplings for space and nutrients. However, the fact that the *Ziziphus* was thriving in the plot shows that shrubs are capable of surviving in the area, and there must be some other factor preventing the argan saplings from growing.

Overgrown plot observations include the presence of many small snails (*Theba pisana)* on a few of the younger offshoots (Figure 17). The snails can negatively affect the argan vegetation and are an agricultural pest in many places. The plot consisted of other vegetation of various species covering the whole of the plot. Most of the plants were tall grasses and were dead. In some areas, vegetation had grown up to 3 ft tall. The short dead grasses and roots created a stable topsoil. There was an abundance of black plastic irrigation tubing that had been discarded and scattered, along with other trash. In several instances, the tubing had been tied onto some of the tree branches. There were also plentiful argan seed shells and nuts lying on the ground below trees.

Loubia plot observations included a secure fencing system that consisted of both stones and large brush. Inside the plot, beans and cane crops were alternated throughout with 2-3 rows of cane and then 5-10 rows of beans. Both crops were dead and dry. The cane plants had been harvested but the beans had not. There was only one argan tree in the plot that had fallen fruit surrounding it. This tree seemed especially peculiar because no other trees had fruits below them, and this tree had approximately 200-300 fallen fruits directly below its canopy zone. According to K. Outalb, many of the trees had already dropped their fruits earlier in the season, so it was likely that this tree had dropped its fruit later than most and had not been collected yet (K. Outlab, personal communication to the author, June 2017). In comparison to the other plots, the Loubia plot had a vast number of thriving weeds growing. Unlike

Figure 18. Crop rows in Loubia plot, Bel Bayad, Morocco.

the Overgrown plot, this plot also contained a vast number of plant species that appeared to be thriving, especially under tree shade. Irrigation tubing lined the rows where crops had been planted. Whether or not this tubing could actually effectively water the crops is undetermined. Argan offshoots near the bases of the trees in this plot were much thicker and more bushy than in the other plots. The soil near trees seemed to be rather stable because of the presence of excess vegetative root systems. However, the soil not near to trees was very loose and not compact.

Mountain plot observations include a very different terrain than the other three plots. The plot was on a hillside where elevation increased in the northern side of the plot. Soil was very rocky and many rocks slid down the hillside when walking across. Near trees roots, soil was more stable. The size of the rocks in this plot were also much larger than the other plots. Although the soil was very loose, it was not because of farming practices of any kind. Donkey and goat feces were present in several places. One man was sitting near the base of a tree in the plot. This plot was much closer in proximity to the village of Tiwrar than the other three plots were to the village of Bel Bayad, and it was alongside a road that cars could drive on. There were a couple of snail

Figure 19. Rocky Hillside of Mountain plot, Tiwrar, Morocco.

shells found in the plot, but no snails living on trees. Most of the young saplings were low to the ground and bushy.

Observations Related to Forest Governance

Overall observations of the Bel Bayad plots related to governance include passing some herds of sheep and goats that shepherds allowed to browse the grounds as well as many goats in trees. Some of the goats were in the tallest branches of the trees approximately 5-6 m high. There were a few plots of land that had temporary huts built from reeds and other materials. K. Outalb informed me that the makeshift huts present in the forest were owned by villagers who would use them during the day and were considered private property. However, the owners of these huts also had permanent homes in the village (K. Outalb, personal communication, June 2017).

Most of these fencing structures were actually unsuccessful at keeping out animals and livestock, as most of the plots I observed had sheep, dogs, or donkeys inside of them. The only fencing structure that seemed to successfully keep out large animals was that of a large stone wall. This was the most permanent looking structure of fencing I observed in the forest. The stone wall surrounded a large field of green peppers that were being grown amongst the argan trees. The fence was approximately 1.5 m tall and inside of this fence was a large cactus fence approximately 2-3 m in height. Most other fencing was either a simple boundary of lined rocks on the ground to mark the edge of a plot or was a wall made of short dead brush with thistles/dead argan branches to prevent animals and/or people from entering. Although it may be difficult or cause injury, I could successfully enter any of the plots I observed, other than the large stone wall. I assume that most animals could also enter the plots because I was able to easily enter them.

Discussion

Exploitation Effects on Argan Regeneration

The Wheat plot contained the greatest number of adult trees yet yielded zero saplings (Figure 10). From this result, we assume that exploitation pressures of some kind affected the plot greatly enough that no reproduction was possible. When comparing this plot to the other three plots, it is evident that the Wheat plot had the greatest amount of overall exploitation (Figure 13).

We can rule out the possibility that the adult trees in the Wheat plot were incapable of reproduction because there were argan shell remains under several of the trees. When looking at Table 2, we see that all three tested exploitation types were heavily or excessively affecting the plot. Because all three factors were so high, we cannot be certain of which factor is the most responsible, but can assume that, likely, the combination of all three factors is responsible for this result.

The Overgrown plot had a slightly smaller sample size than the Wheat plot with 45 tested adult trees, but it had 3 reproductive adults that were responsible for the propagation of 4 saplings (Figure 10). There was not one particularly outstanding difference between the type of exploitation most affecting the Wheat plot and the Overgrown plot (Figure 13), however, the Overgrown plot had slightly less agricultural impact as well as less grazing pressure. Overall, the Overgrown plot had the second greatest density of saplings present (Figure 14 & 15).

The Loubia plot had the least amount of grazing pressure because of its structured fencing surrounding the plot. However, the plot had only one sapling, which can most likely be attributed to the heavy agricultural impact and consistent soil disruption for farming practices (Figure 13). It is not likely that seed collection greatly affected the plot's ability to reproduce because, with or without seed collection pressures, the frequent and heavy farming would eliminate young seedlings. It is likely that the cane plants that were grown alternating the bean plants helped provide shade for beans. This shading could have impacted young seedling argan growth, but this is unlikely because cane was only grown temporarily. Although we cannot be certain that the irrigation system lining the Loubia plot was effective, it likely explains why unwanted vegetation and weeds were thriving in the plot. We can assume that the Loubia plot most likely had the greatest amount of water accessible to possible seedlings or saplings.

Despite the steep terrain and unstable soil in the Mountain plot, young saplings were able to propagate in some areas. The unstable soil within the plot prevented farming practices and was likely the reason that young saplings were able to survive. Even so, most of the saplings best thrived in areas near to roots of adult trees or in areas where soils were more stable. This suggests that soil stability is important for sapling growth, and although the mountain side has extremely unstable soil conditions, small pockets of stable soil provided a better environment than the other three plots which had more stable soil but also more detrimental exploitation. From this observation we infer that, in the absence of agricultural pressures in the Wheat, Overgrown, and Loubia plots, we would expect to see greater reproductive ability than the Mountain plot because of their soil stability. This validates the significance of agricultural impacts on argan reproduction.

Sapling Density Analysis and Inferences

In the Wheat plot, the lack of sapling density is associated with high overall exploitation. (Figure 14 & 15). An educated prediction would suggest that the more exploitation a plot undergoes, the less likely the plot is to have reproductive ability. This prediction is confirmed in the lack of saplings present in the Wheat Plot data (Figure 14). Although this pattern is consistent for the Wheat, Overgrown, and Mountain plots, the Loubia plot data does not fit this trend. The Mountain plot's sapling density was exceptionally greater than the density of any of the other plots (Figure 14), and it was the only plot without agricultural pressures (Figure 13). If we instead consider each type of exploitation individually, we see that the agricultural exploitation level directly correlates with all four plots' sapling densities (Figure 13 & 15). In fact, agricultural exploitation level was the only factor that consistently correlated with sapling density results (Figure 13 & 15). The trendline associated with grazing (Figure 15.B.) shows that grazing pressures have very little impact on sapling densities and are unlikely the factor most affecting reproduction.

Sapling densities actually seemed to increase with higher seed collection pressure (Figure 15.C.). It is extremely unlikely that seed collection is actually helping more trees reproduce, so instead we can conclude that the effect of seed collection on reproduction is very insignificant. From the inverse relationship between agricultural pressure and sapling densities, where low exploitation is associated with high sapling densities and high exploitation is associated with low sapling densities, we can can infer that agricultural exploitation has the greatest impact on an argan forest plot's ability to naturally reproduce.

Sapling Dispersal in Relation to Exploitation

The saplings that were present in the Overgrown and Loubia plot were all within 10 ft of the parent trees, (Figure 16) while the mountain plot had the greatest number of saplings present between 10-20 ft from the base of the parent trees. This shows a lack of dispersal ability to reach beyond the immediate area surrounding the tree and suggests that a natural dispersal range is larger than the small ranges achieved by the Overgrown and Loubia plots. It is likely that agricultural pressures are responsible for this result because farmers avoid tilling areas directly surrounding the trees where they could injure trees or hit root systems. The lack of agricultural pressure near the trees would then explain why the Mountain plot had a much greater dispersal range for reproduction.

Study Results Comparison with Government Regulations

Building Structures and Fences

Forest regulations allow users to create temporary fences around their designated plots at harvest time. When observing various farm plots near Bel Bayad, I noticed several different types of temporary fencing structures. If it is inferred that the reasoning for this regulation is to provide protection of farmers' crops from animals grazing, it makes sense that users would be allowed to create such fences. If we consider the environmental impacts that creating physical barriers within an ecosystem has, it is understandable that the regulation would require the fencing to be temporary. In my opinion, the fencing surrounding the Overgrown plot fit within these regulations. However, the stone structure surrounding parts of the Loubia plot seemed to be more permanent. The weedy brush barrier of the Overgrown plot allowed for small insects, reptiles, or rodents to pass through without allowing large grazing animals to enter. On the other hand, a stone wall, such as the Loubia plot's, is much more impenetrable to these other life forms.

The large stone wall surrounding the green pepper field seemed to be especially permanent. It not only prevented large and small organisms from entering, it also prohibited the villagers from access to the argan trees for fruit collection, which is a right they are entitled to under Article 3 of the King's decree on argan forests (Dahir on the protection of the delimitation of argan tree forests 1925).

There were also makeshift huts scattered throughout the forest. Some of the huts had their own fencing system around them. In the case of the large stone wall and the huts, it appeared to me as if they had been there for years, and thus would fall under the category of ‘permanent’. When huts or other structures are built within the forest, it creates uneven areas of exploitation. An example of this might be a path that is frequently used leading up to the hut or the area directly around the structure. Fires are another concern regarding the huts. Forest areas are very dry, so if people are using the huts to prepare meals, with a stove or open flame, it presents a considerable fire hazard. Flammable materials and huts have a restricted distance that they are supposed to be from the argan forest. However, if it is considered safe by the forestry service, villagers are allowed to put up erect tents.

Impacts of Grazing

The argan forests are important to villages, not just for growing crops and collecting argan products, but also for food for grazing livestock. Shepherds depend on many of the forest plots in order to provide grazing areas for their herds. It is understandable that farmers would not want animals grazing within their plots, however, without the argan forests for grazing, there are few other places where animals have vegetation to graze on.

Heavy grazing is also detrimental for the argan trees. It reduces the trees’ fitness and can limit their ability to produce bountiful fruit yields. However, goats have been climbing the trees for many years, and the trees have still been able to effectively produce fruits. The trees provide food for the goats and the goats help the tree with seed dispersal.

Although goat grazing may have negative effects on farmers crops, it is essential that herds are allowed to graze within the argan forest areas.

Conservation Regulation Suggestions

Permanent Structures in the Forest

I believe that secure tents and other concealed flammable structures should be forbidden from the forest area. They present a serious fire danger because a single tent starting on fire could wipe out a vast large area of an argan forest. Because of the semi-arid climate and limited water resources, it is especially important that such fire risks are avoided. However, I do not think that all tents and shelters should be prohibited because their main purpose is to provide a resting area for villagers out of the sun and heat. I do think that there should be tighter restrictions on these structures to ensure that fire hazards are avoided. Regulations could include the allowance of tents that have at least one open side to prevent users from using their tents for cooking or smoking without being seen. Tents should also not be allowed to stand in one area for longer than a week in order to prevent the detrimental environmental impacts these structures could have. This allows the plot's area to sustain a healthier ecosystem for plants, insects, and other organisms that live in the forests.

Temporary fencing structures should be allowed, and I agree with the King's decree pertaining to fencing for harvest time. However, these regulations must be enforced. The stone fences that surround farm plots such as the Loubia plot or that of the green pepper field must be regulated. They create a large permanent barrier that restricts access for villagers and create an unnatural ecosystem barrier. For conservation regulations to work effectively, they must be compulsory. There are other fencing structures that can keep out grazing livestock without the negative effects a more permanent structure impedes.

Allowing Grazing Within Plots

Partially related to fencing regulations, is the permissibility of goats and other livestock to graze within forest plots. If every farm plot restricted livestock access by creating semi-permanent fencing barriers, there would be very little area for the animals to graze. This is why it is important that fences only be temporary. Regulation should require that an accessible plot entrance is available for livestock to enter during non-harvest seasons. Animals should be allowed to graze on the argan trees intermittently. This allows the trees time to regrow and regenerate without overly exhausting the trees' resources. It should also be the shepherd's responsibility to keep livestock away from farmers' crops when allowing their herds to enter plots.

Agricultural Practices

Continuous farming of soils beneath argan trees not only deteriorates the soil nutrients within the forest, but it also prohibits generation of already rare natural propagation. It is important to consider the ecosystem services that the forests provide for communities when making laws. If only considering environmental impact, it would be best to prohibit any farming within argan forests. However, considering societal needs of food to eat, shade to grow crops, and land for farming, all are important when creating regulations. I agree with the Moroccan Kingdom's decision to allow villages use of argan forests and think that the usufructuary system seems to be the most reliable choice of governance. Although, I disagree with the implementation and enforcement of laws if the ultimate goal is to protect *A. spinosa* for conservation purposes.

The MAB arganeraie was enacted to ensure argan trees are not overexploited and that the forest systems can remain sustainable into the future. If the ultimate goal is to make sure argan trees are available as they are today, there must be changes to regulation. The most important change, in my opinion, is to reduce agricultural impacts on forest plots.

Lack of Young Forest Growth

The main point of concern I had when observing the current argan forest plots was the lack of young generational trees. There were very few young argan saplings present and even fewer saplings that were older and closer to maturing. The argan tree takes a long time to fully mature, so it is pertinent that young trees are planted immediately. When I was discussing the age of the argan forest with the Outalb family, I was shocked by some of the responses. They agreed that the trees had not been planted, but simply "just grow naturally". After asking about the age of the trees, I mentioned that they all appeared to be rather old and about the same age. If the trees all reach a maximum lifetime (~200 years) at a similar time, there could be a massive decline in fruit availability for many years. In order to preserve a sustainable forest system, it is important to have young, middle-aged, and old trees so that the forest can continue to replenish itself.

Suggested Management Proposal

The following are suggestions I have that could be added to the current management plan based on my study and observation of the argan reserve in Morocco:

1. There are designated forest plots that are never to be farmed and are meant solely to provide natural argan ecosystems that serve as wilderness sanctuaries.
    a. These preserve areas provide forest species natural environments and promote survival and genetic diversity of species.
    b. The size and number of plots should be decided by the forestry service based on village livestock numbers and population sizes.
2. Every farmed plot must be made available to livestock for at least a 3-month period (1 season) for grazing to prevent uneven grazing habits amongst plots.
    a. Exceptions to this law exist only if trees are deemed overexploited and need time for regrowth.
3. There are designated forest plots that are meant for livestock grazing during harvest seasons so that herds still have places to graze when other plots are barricaded off for harvesting crops.
    a. These plots must remain ungrazed during seasons when livestock have access to farmed plots in order to promote growth within preserved areas.

4. Every farm plot must be farmed for a maximum of 10 consecutive years. In between these 10 year periods, argan seedlings are to be planted and protected from agricultural or grazing practices for two years to encourage sustainable growth and cultivation.
5. Plot users are responsible for maintaining a natural age range of trees by allowing young trees to grow and develop.
    a. If the forestry service finds plot users are dismissing this regulation, they may enforce an immediate 2 year period where seedlings must be planted.
    b. The tolerance of an age range of trees is determined appropriate by the forestry service.
6. A member of the forestry service is responsible for undergoing biannual checks of forest plots to ensure proper conservation management enforcement.
7. All fencing of plots must be temporary. Regulation of this law is enforced and punishable by law.
    a. This includes materials such as brush, trimmed branches, sticks, plants, and stone barriers that are less than 10 cm in height.
    b. Fences, under no circumstances, can prohibit the entry of other forest beneficiaries.

Without changes to the current argan forest conservation plan, future sustainability is at stake. It is important that the Moroccan government, village leaders, and communities work together to maintain healthy argan forest systems. The future of the argan forests, is the responsibility of all people.

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